

CECW-ET

**DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000**

EM 1110-1-4012

Manual
No. 1110-1-4012

15 November 2001

**Engineering and Design
PRECIPITATION/COAGULATION/FLOCCULATION**

Table of Contents

Subject	Paragraph	Page
CHAPTER 1		
INTRODUCTION		
Background	1-1	1-1
Scope	1-2	1-1
CHAPTER 2		
PRECIPITATION		
Introduction	2-1	2-1
Theory and Discussion	2-2	2-3
CHAPTER 3		
HYDROXIDE PRECIPITATION		
Introduction	3-1	3-1
Advantages and Disadvantages of Hydroxide Precipitation	3-2	3-2
Hydroxide Precipitation Using Lime	3-3	3-2
Hydroxide Precipitation Using Caustic Soda	3-4	3-4
Hydroxide Precipitation Using Magnesium Oxide	3-5	3-6
Process Performance	3-6	3-6
CHAPTER 4		
SULFIDE PRECIPITATION		
Introduction	4-1	4-1
Advantages and Disadvantages of Sulfide Precipitation	4-2	4-2
Soluble Sulfide Precipitation (SSP)	4-3	4-3
Insoluble Sulfide Precipitation	4-4	4-4
Calcium Sulfide Precipitation	4-5	4-6

Subject	Paragraph	Page
CHAPTER 5		
CARBONATE PRECIPITATION		
Introduction	5-1	5-1
Advantages and Disadvantages of Carbonate Precipitation	5-2	5-1
Carbonate Precipitation Using Calcium Carbonate	5-3	5-2
Carbonate Precipitation Using Sodium Carbonate	5-4	5-3
CHAPTER 6		
OTHER PRECIPITATION		
Introduction	6-1	6-1
Xanthate Precipitation	6-2	6-1
Combined Precipitation	6-3	6-2
CHAPTER 7		
COAGULATION AND FLOCCULATION		
Introduction	7-1	7-1
Theory and Discussion	7-2	7-2
CHAPTER 8		
COAGULANTS, POLYELECTROLYTES, AND COAGULANT AIDS		
Introduction	8-1	8-1
Inorganic Coagulants	8-2	8-1
Polyelectrolytes	8-3	8-3
Polyelectrolytes vs. Inorganic Coagulants	8-4	8-3
Coagulant Aids	8-5	8-4
Chapter 9		
MIXING—GENERAL DISCUSSION AND THEORY		
Introduction	9-1	9-1
Rapid Mixing	9-2	9-2
Rapid Mixing Vessel Considerations	9-3	9-2
Flucculation Mixing/Agitation	9-4	9-3
Chapter 10		
TREATABILITY TESTING		
Introduction	10-1	10-1
Determination of Optimum pH Level	10-2	10-1
Determination of Coagulant and Coagulant Aid Dosage Rates	10-3	10-2
Determination of Settling Rates	10-4	10-4
Determination of Sludge Characteristics	10-5	10-4
Oxidation Considerations (Iron and Manganese Removal)	10-6	10-5

Subject	Paragraph	Page
Chapter 11		
PRE-TREATMENT REQUIREMENTS		
Introduction	11-1	11-1
Flow Equalization	11-2	11-1
Oil and Grease Removal	11-3	11-4
Chromium Reduction	11-4	11-4
Cyanide Destruction	11-5	11-4
Complexing/Chelating Agent Removal	11-6	11-5
Chapter 12		
EQUIPMENT REQUIREMENTS		
Introduction	12-1	12-1
Equalization Tank/System	12-2	12-2
pH Control System	12-3	12-2
Tank/Reactors	12-4	12-3
Rapid Mixers	12-5	12-4
Flocculators/Agitators	12-6	12-5
Chemical Feed Equipment	12-7	12-8
Sludge Dewatering Equipment	12-8	12-8
Miscellaneous Equipment	12-9	12-8
Chapter 13		
P/C/F SYSTEM COSTS, STARTUP, AND OPERATIONS		
Introduction	13-1	13-1
System Costs	13-2	13-1
Pre-Startup Checkouts	13-3	13-6
Pre-Startup Testing	13-4	13-7
Startup	13-5	13-7
Field Training	13-6	13-8
Shutdown	13-7	13-9
Operation and Maintenance Manual Updates	13-8	13-9
Operation	13-9	13-11

EM 1110-1-4012
15 NOV 01

Subject	Page
APPENDIX A REFERENCES	A-1
APPENDIX B LIST OF ABBREVIATIONS	B-1
APPENDIX C DESIGN EXAMPLE	C-1

LIST OF TABLES

Subject	Table	Page
Theoretical Solubilities of Hydroxides, Sulfides, and Carbonates of Selected Metals in Pure Water at 25°C.	2-1	2-3
Solubility Product Constant vs. Solubility	2-2	2-5
Advantages and Disadvantages of Hydroxide Precipitation	3-1	3-3
Comparison of Hydroxide Reagent Properties	3-2	3-7
Advantages and Disadvantages of Sulfide Precipitation	4-1	4-3
Advantages and Disadvantages of Carbonate Precipitation	5-1	5-2
Advantages and Disadvantages of Xanthate Precipitation	6-1	6-2
Relative Coagulating “Power” of Cations	7-1	7-2
Advantages and Disadvantages of Alternative Inorganic Coagulants	8-1	8-2
How Viscosity Varies with Temperature	9-1	9-1
EPA Assumptions Used to Develop Costs	13-1	13-1
Cost for Continuous Flow P/C/F System using Hydrated Lime	13-2	13-3
Cost of Continuous Flow P/C/F System using Soluble Sulfide Precipitation	13-3	13-4
Cost of Continuous Flow P/C/F System using Sodium Carbonate Precipitation	13-4	13-5

LIST OF FIGURES

Subject	Figure	Page
Continuous Metals P/C/F System	2-1	2-1
Solubility of Metal Hydroxides and Sulfides as a Function of pH	2-2	2-2
Metal Chelate with EDTA	2-3	2-6
Typical Titration Curve for an Acidic Waste Stream	3-1	3-5
Xanthate Chemical Structure	6-1	6-1
Charge Neutralization (Coagulation)	7-1	7-1
Flocculation	7-2	7-2
Mechanisms of Coagulation and Flocculation	7-3	7-3
Jar Test Analysis	10-1	10-3
Alternating Flow Diversion Equalization System	11-1	11-1
Intermittent Flow Diversion System	11-2	11-2
Completely Mixed Combined Flow System	11-3	11-2
Completely Mixed Fixed Flow System	11-4	11-3
Turbine Mixer in a Baffled Tank	12-1	12-4
Propeller Mixer	12-2	12-5
Mixer Clarifier	12-3	12-6
Inclined Plate Clarifier	12-4	12-7